Challenges and implementation approaches of shingled heat assisted magnetic recording (HAMR) for 10 Tb/in^2 data storage

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***Abstract*— Heat Assisted Magnetic Recording (HAMR) has been considered to be the most promising candidate for next generation magnetic recording technology beyond 1.5 Tb/in^2 and it may extend the recording density to about 5 Tb/in^2. However, it may face challenges to further increase the areal density to 10 Tb/in^2 and beyond due to the difficulties to further reduce the thermal spot size of < 50 nm because of difficulties in fabricating even smaller near field transducer (NFT) with enough efficiency. In this paper, we propose to use wide NFT to write narrower HAMR tracks by writing tracks sequentially overlapping with previous tracks (i.e., shingling) so as to increase HAMR track density and areal density in total. The improvement in writing profile curvature/ field gradient at write corner allows further track density increase while keeping the linear density from being reduced significantly. It is demonstrated by experimental and simulation results that the total areal density is able to be increased with significantly increased track density for improved shingled HAMR without too much sacrifice of linear density. The advantages of the proposed shingled HAMR include writing narrow track width with larger NFT/ thermal spot size and ease of NFT fabrication for better cost/ yield control.**

Index Terms—**Heat assisted magnetic recording, write bubble, bit curvature, areal density**

I. INTRODUCTION

Heat assisted magnetic recording (HAMR) [1] has been considered to be the most promising candidate for next generation magnetic recording technology beyond 1.5 Tb/in^2. After many years of efforts, the HDD industry has so far achieved demonstration of HAMR technology with areal density of over ~1 Tb/in^2 (≈ 2 Mbpi × 5000 ktpi) on spinstand [2]. In HAMR, a small portion of media (high coercivity at room temperature) is heated to high temperature (T) (around Currie temperature (Tc)) so that the cercivity (Hc) of the heated region is significantly reduced and the magnetization of the heated region is able to be switched by a smaller writing field (which is significantly smaller than media room temperature coercity) from the head pole. The switched magnetic region is then frozen to form a switched bit upon the cooling process. The write bubble is resulted from both thermal and magnetic field footprint. The most significant advantage of HAMR is that a higher linear density (even higher than current demonstration of 2 Mbpi linear density) can be achieved due to much higher total effective writing field gradient because of the increased product of high thermal gradient (dT/dx) (x: down track position) and steep coercivity drop (dHc/dT at ~ Tc) than conventional head field gradient.

For conventional HAMR, the tracks are written side by side without overlapping each other (i.e, overlapping is undesirable). The track width is limited to thermal spot size. So far, the highest track density of ~500 ktpi as demonstrated was achieved by small thermal spot size of ~50 nm. To further improve the track density of higher than ~500 ktpi (track pitch < ~50 nm), it is required to reduce the thermal spot size. However, it is difficult to further reduce the thermal spot size due to the difficulties in fabricating even smaller NFT with enough efficiency.

This paper proposes to use wide near field transducer (NFT) to write narrower HAMR tracks by writing tracks sequentially overlapping with previous tracks (i.e., shingling) so as to increase track density and areal density.

II CONCEPT & EXPERIMENTAL VERIFICATION OF SHINGLED HAMR

A). Concept of Shingled HAMR

Fig. 1 shows schematic of proposed HAMR writing process. Recorded HAMR tracks are sequentially overlapped with previous tracks with overlapped thermal spots (/write bubbles) for both bits and tracks. It is shown that higher track density (/narrower track) can be achieved despite larger spot size. Since high field gradient can be achieved for both down track and cross track directions, it is ideally possible to increase track density as high as linear density. However, on the other hand, SNR and linear density will be sacrificed with increasing track density, especially for overlapping more than 50% due to curved write bubble profile. An overall maximum areal density gain (>2) could be

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achieved at certain optimized track overlapping percentage. Another important advantage of proposed HAMR writing process is the ease of NFT fabrication (meaning better cost/ yield control) for larger NFT size because of the use of large thermal spot size allowed.

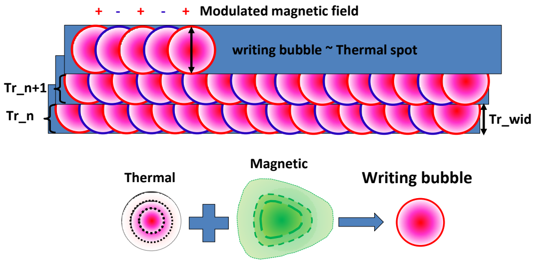

Fig. 1. Schematic of shingled HAMR (upper) and formation of writing bubble by thermal and magnetic profiles (lower)

B). Experimental verification of Shingled HAMR

Fig. 2 shows MFM image of shingled HAMR tracks (by far field laser beam) with different track pitches (from 3 um down to 125 nm). It can be seen that SNR degrades for narrower tracks due to curved bit shape. Considering the compromise of linear density with increased track density, we can see an increase in overall areal density gain. With a circular 3 um thermal spot profile, written tracks as narrow as 125 nm (~4% of original unshingled track width) are clearly discernable by MFM

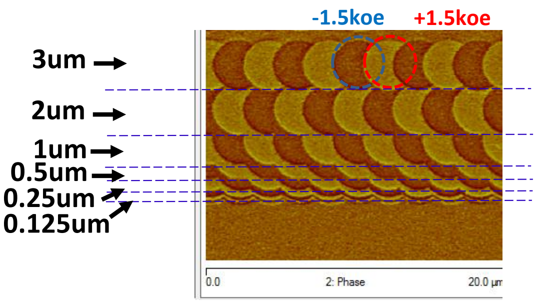

Fig. 2. MFM image of shingled HAMR tracks with different track pitches

III Shingled HAMR: further improvement

There are two approaches to improve the linear density limit for shingled HAMR. 1). To improve the curvature of thermal and write bubble profile; 2). To improve total field gradient, especially at effective write corner.

Fig. 3 shows schematic of shingled HAMR with improved effective write profile of idea case. Both track density and total areal density can be increased.

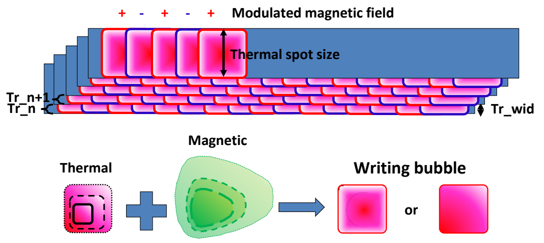

Fig. 3. Schematic of shingled HAMR with improved effective write profile (upper) and formation of improved writing bubble by improved thermal and magnetic profiles (lower)

To further understand the feasibility of write profile improvement, theoretical simulations of thermal profiles were also carried out. Fig. 4 shows simulated thermal footprint of corner curvature for improvement vs. conventional design. Light sources for the two designs (improvement vs. conventional) are also shown in insets. It can be seen that higher corner tangential angle can be achieved for improvement design. Higher track density (smaller track width) and increased total areal density can therefore be achieved for improvement design.

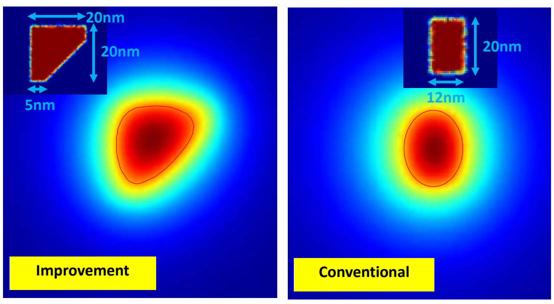

Fig. 4. Simulated thermal footprints for improvement design (left) vs. conventional design (right)

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